INTEGRATION OF PORTABLE AIR BLOWERS INTO THE LEGS OF A CONSTANT WEAR IMMERSION SUIT

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EXECUTIVE SUMMARY

Under contract to DRDC-Toronto, Mustang Survival Corp. conducted a project to integrate portable air blowers into the leg regions of a Modified Aircrew Constant Wear Immersion Suit. The Modified Constant Wear Immersion Suit has an adjustable style neck seal. The primary aim of this project is to develop a system that will circulate ambient air within the suit microenvironment thereby displacing sweat-laden air out of the open neck seal. It is hypothesized that the resulting increase in temperature and water vapor gradients will concurrently increase the dry and evaporative heat loss from the skin and enhance aircrew comfort.

An initial experiment, using a high-flow and high-pressure blower, was performed to quantify the airflow characteristics of the suit system and provide evaluation criteria for the blower selection process. The following suit system configurations were studied in both sitting and standing positions:

- Modified Constant Wear Immersion Suit with Non-Uniform Breathable Foam Liner;
- Modified Constant Wear Immersion Suit with Non-Uniform Breathable Foam Liner and CF Helicopter LP/SV; and
- Modified Constant Wear Immersion Suit with Non-Uniform Breathable Foam Liner, CF Helicopter LP/SV and PCU-15/P Parachute Harness.

The back-pressure range for all of the configurations above was measured as 0.83 to 10.28 in H_2O. Using the back-pressure range as a criterion, centrifugal or radial blowers were selected in lieu of axial fans due to the high pressure characteristics. The blowers purchased for the prototype were Micronel Miniature Radial Blowers having a maximum static pressure capability of 3.62 in H_2O. Preliminary testing revealed that the use of spacer fabrics in the liner system could be implemented to reduce the back-pressure significantly. In the most restrictive configurations, maximum back-pressures on the order of 1.25 to 1.75 in H_2O were measured when spacer was used. A portable power supply system having variable voltage was also purchased for the development.

Several experiments were conducted to validate the blower selection and to determine the necessity for and location of spacer fabric in the liner system. Back-pressure testing of a simulated full coverage (torso, arms and legs) spacer liner revealed that such a system was very effective in reducing the overall back-pressure. However, when spacer fabric was integrated with the Non-Uniform Breathable Foam Liner in regions highly susceptible to restriction of airflow, comparable back-pressure reductions were attained.

The blowers were integrated to the leg regions of the Modified Constant Wear Immersion Suit. A custom blower pocket was sewn to each ankle and a piece of spacer fabric was used to permit airflow to the inlet port. Airflow from the blowers was routed into the suit via a urethane elbow that was welded to urethane laminated on the suit shell. A custom pocket was fabricated for the portable power system, which was integrated with the CBR Blower mounting bracket on the CF LP/SV. Wiring tunnels

were sewn into the existing seams on the outer leg and across the abdomen to connect the power supply to the blowers. Finally, a Non-Uniform Breathable Foam Liner was modified to incorporate spacer fabric over the chest, abdomen, hips, thighs and ankle regions. The foam and outer Nomex® lining were removed from these regions while the inner Britex® lining was maintained to prevent the abrasive surface of the spacer from contact with the skin.

Testing of the final prototype system provided evidence of drastic reductions in back-pressure comparable to a simulated full coverage spacer liner. In the most restrictive configuration (full ensemble, standing) the back-pressure and airflow were measured to be 1.94 in H_2O and 13.25 CFM respectively. A preliminary evaluation of the thermal benefit of the system also provided favorable results. A subject rested with no cooling for one half hour in an ambient environment (25°C, 50% RH) and was then provided with cooling from the portable blowers for one half-hour. The average skin temperature of the subject was noted to have decreased by over 2°C and the average steady state heat loss was observed to have increased by approximately 80%.

The prototype demonstrates the successful integration of portable blowers to the Modified Constant Wear Immersion Suit system. However, additional testing is necessary to determine the statistical significance of the results presented herein. Furthermore, to validate the physiological benefit of the system extensive human subject testing is required. A liner development would be prudent to identify the most efficient spacer configurations necessary to maximize the airflow in the system and an investigation is required to develop water activated flow interrupters to seal the suit upon immersion. Finally, the impact of the integrated blowers on cockpit compatibility would necessarily be addressed prior to certification for airworthiness.

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1. INTRODUCTION

Mustang Survival was awarded a tasking from DRDC-Toronto under the standing TIES contract W7711-01-7717, Requisition Number 7711-03, to integrate portable air blowers into the leg regions of a Modified Constant Wear Immersion Suit [1, 2].

This project was initiated as part of the ongoing pursuit of a new and improved aircrew immersion suit. Whereas heat stress is a universal problem with such immersion suits, it is typically addressed in high-speed (jet) aircraft using high flow rates of conditioned air. However, there is not, as of yet, a simple, lightweight and portable system for cooling helicopter aircrew. The intent of this project was to add small portable blowers to the leg regions of the immersion suit to induce a flow of ambient air that enters the bottom of the suit and flows next to the skin, exiting at the adjustable neck seal. It is hypothesized that this airflow would reduce both the temperature and relative humidity in the suit microenvironment thereby increasing the temperature and water vapor pressure gradients between the skin and microenvironment. Increasing these gradients will increase the dry and evaporative heat loss from the skin surface and as a result enhance aircrew comfort.

Ultimately, blowers in the legs of the Constant Wear Immersion Suit would be required to seal upon immersion. It is envisaged commercial-off-the-shelf water-activated flow interrupters could be incorporated between the blower(s) and the suit. However, the development of such a system was beyond the scope of the current service contract to investigate the dry thermal benefit of portable blowers in the legs of the suit.

The following is a summary of the statement of work (SOW) proposed for this service contract [3]:

1. Investigate small, low profile, light-weight, low power consuming, portable blowers that could be integrated to the Modified Constant Wear Immersion Suit system;
2. Modify an existing Modified Constant Wear Immersion Suit to accommodate the selected blowers;
3. Conduct a preliminary investigation of the flow rate and distribution of air through the Modified Constant Wear Immersion Suit system when worn by subjects with the neck seal adjusted to the maximum open position and under the following conditions;
   a. Constant Wear and Thermal Liner standing;
   b. Constant Wear and Thermal Liner sitting;
   c. Constant Wear, Thermal Liner and Canadian Forces (CF) Life Preserver/Survival Vest (LP/SV) standing;
   d. Constant Wear, Thermal Liner, and CF LP/SV sitting;
   e. Constant Wear, Thermal Liner, CF LP/SV and CF Helicopter Harness standing;
   f. Constant Wear, Thermal Liner, CF LP/SV and CF Helicopter Harness sitting;

4. Where necessary and feasible, incorporate spacer materials inside the suit system to increase airflow; and
5. Prepare a final report detailing the blower(s), modifications to the suit system and data from the air flow distribution.

2. SUIT SYSTEM BACK-PRESSURE

The first task in the SOW was to investigate small, low profile, light-weight, low power consuming, portable blowers that could be integrated with the Modified Constant Wear Immersion Suit. To select a blower it was necessary to quantify the specifications for ideal performance in the system. The back-pressure of the suit system, when worn in various positions and with additional aircrew life support equipment, was determined to be the primary constraint for blower selection.

In order to determine the back-pressure of the suit system, a simple experiment was designed. Figure 2-1 below is a diagram of the experimental apparatus and setup.

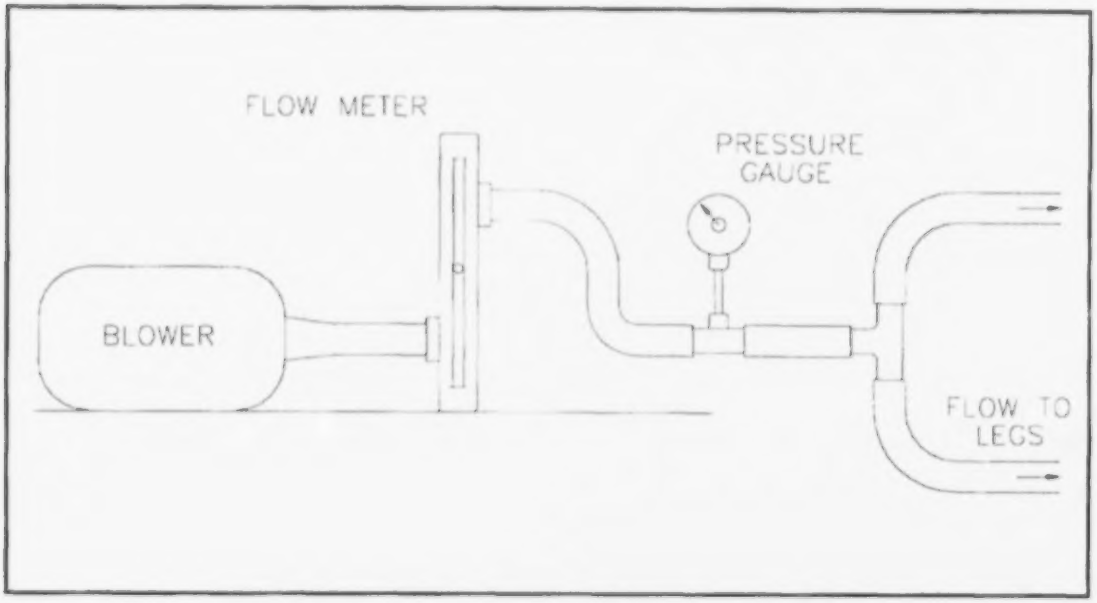

Figure 2-1 Back-Pressure Experimental Setup

An arbitrary blower, with high pressure and flow, was chosen to distribute air throughout the system. To determine the back-pressure of the suit, the flow pressure was first measured with the hoses disconnected from the suit inlet ports, the "free-flow" pressure. The free-flow pressure subtracted from the pressure measured with the hoses connected to the suit system provided a measurement of the internal back-pressure. The flow into the suit was also measured during the experiment so that the suit's resistance, with units of P*s/L, could be calculated. A preliminary test was conducted with a Size 7 Constant Wear Immersion Suit [4]. It was modified with ports in the lower legs as air inlets and a trimmed neck seal to simulate the open area of the adjustable neck seal on the Modified Constant Wear Immersion Suit. The subjects wore both the

suit and a Non-Uniform Breathable Foam Liner [5, 6, 7 and 8]. Two of the subjects wore the Size 7 suit with a Size 9 liner while the third subject wore the Size 7 suit with a Size 6 liner. Figure 2-2 below is a plot of the back-pressure in the various configurations.

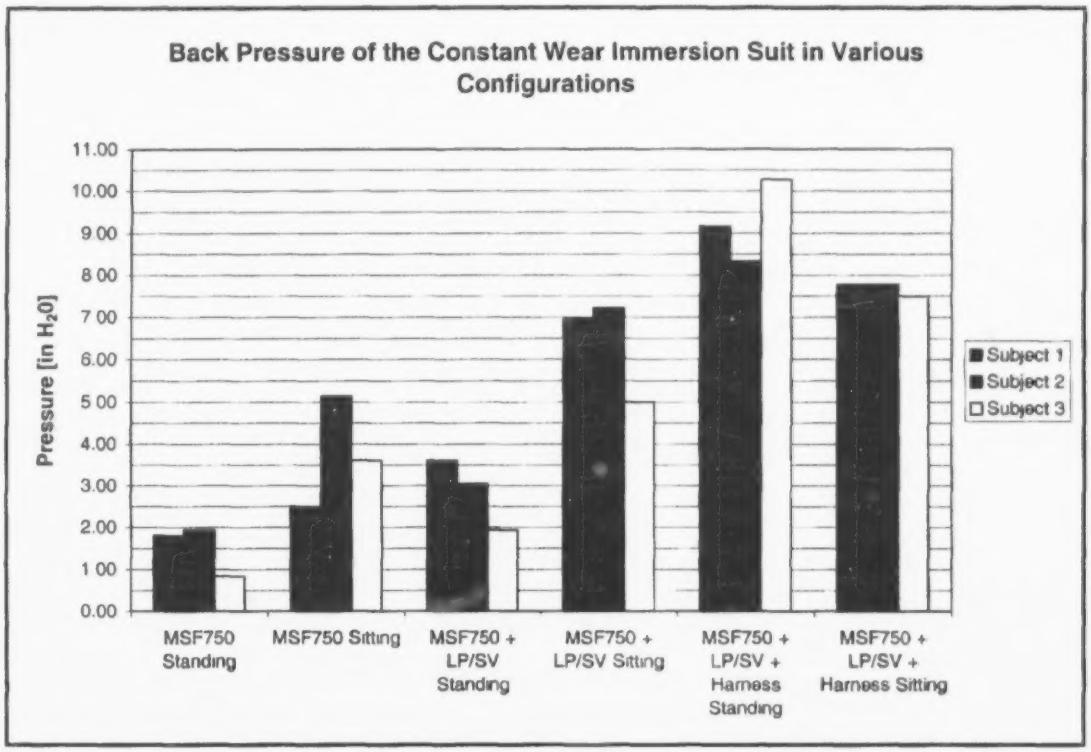

Figure 2-2 Back-Pressure Experimental Results

It was clear during testing that the fit of the suit and adjustment of the LP/SV and harness were critical to the back-pressure measured from the system. The system pressure also exhibited posture dependence as one subject noted significant changes in the measured back-pressure when simulating a straining maneuver with the abdominal muscles. Furthermore, it was possible to position the head in different positions to effect the flow out of the open neck seal. It is important to note that in contrast to the other configurations, the back-pressure of the system is lower while sitting when wearing the harness. It is hypothesized that the increase in suit resistance while standing is because the harness is configured to be tight fitting while in the sitting position. When standing, the crotch straps are strained by the shoulder straps, which extend as the torso section straightens.

This experiment demonstrated the ability to quantify the internal pressure of the suit system when worn in various configurations. The range of pressure measured, 0.83 to 10.28 in H_2O, was then used to validate the specifications for the blower.

3. INVESTIGATION OF SYSTEM COMPONENTS

The section below details selection of the blowers and associated power system.

3.1 Blower Selection

The intent of the blower system is to force humid air from inside the suit microenvironment out through the open neck seal. The principle specifications for the blower were identified in the service contract proposal as small, low profile, light-weight, lower power consuming and portable. In terms of performance criteria, the limiting factor to airflow is the internal pressure of the suit system. The ideal candidate blower would provide the highest possible airflow against the inherent back-pressure.

A blower investigation was conducted to identify a vast range of fans and blowers that might be capable of meeting the intended specifications. These were then evaluated using a ranking matrix in which each criterion was given specific weighting. Flow and pressure were given the highest consideration. The other variables identified were power consumption, size and weight. The maximum power consumption allowable for the selected blower was based on the capacity of the battery pack that was selected and this was an iterative process as both the blower and battery pack were somewhat interdependent. There was not a maximum weight criterion quantified for this project and therefore minimizing the weight was the principal concern. The size variable was used as a "select out" criteria. Blowers that could not be mounted to a 100 X 100-mm area were not considered. This value was as determined from investigation of mounting area available on the leg regions of the smallest size of the Constant Wear Immersion Suit.

The primary types of air distribution systems that were identified were radial fans and centrifugal blowers. While some of the radial fans reported airflow in excess of 100 CFM, none were able to perform against back-pressures above 0.42 in H_2O, significantly lower than the lowest back-pressure recorded for the suit system, 0.83 in H_2O. Consequently, centrifugal blowers were identified as the best type of system to meet the design criteria.

Two blowers were found with performance features within the ranges identified for this project. The first blower was a miniature radial blower manufactured by Micronel U.S. and the specifications are provided in Table 3.1-1 below. The Micronel blowers were purchased for use during the test and evaluation component of the project. Although the Micronel blowers were not rated to the maximum back-pressure that was identified during preliminary testing, 10.28 in H_2O, it was postulated that this back-pressure would be sufficiently reduced with the use of spacer materials on the final prototype. Figure 3.1-1 is a photo of the Micronel blower used for the prototype.

Table 3.1-1 Micronel Miniature Radial Blower Specifications

Part Number	U97EM-012KK-3
Manufacturer/Distributor	Micronel Ltd.
Voltage	12 VDC
Current	630 mA
Airflow Rate	20.3 CFM at 0 in H_2O
Static Pressure	3.62 in H_2O
Size	ϕ98 X 75 mm
Weight	0.210 kg

Figure 3.1-1 Micronel U97EM-012KK-3 Miniature Radial Blower

The second blower was also a radial blower. Manufactured by Ametek Rotron Technical Products, its specifications are provided in Table 3.1-2 below. Although the back-pressure performance features of the Ametek blower appeared significantly better than the Micronel blowers, there were several reasons that the Ametek blowers were not selected for testing and evaluation. In particular, the blower's minimum operating power requirement is rated at approximately 16-Watts. There were very few portable power supply systems reviewed capable of supporting two such blowers for an extended period of time. Very short operating periods would negatively impact the effectiveness of the blower-integrated system.

Table 3.1-2 Ametek Rotron Brushless Blower Specifications

Part Number	119349
Manufacturer/Distributor	Ametek Rotron Technical Products
Voltage	12 VDC

Current	1.33 A (Minimum)
Airflow Rate	18 CFM at 0 in H_2O
Static Pressure	10 in H_2O
Size	ϕ76 X 71 mm
Weight	Approximately 0.900 Kilograms

NOTE
The blowers are not waterproof, do not immerse in water.

3.2 Power Supply Selection

The power supply selection was driven primarily by the specifications of the blower systems that were evaluated. All of the blowers investigated were rated for operation at 12VDC or 24VDC. Because it was unclear what type of blower would ultimately be chosen, a variable voltage, portable battery pack was purchased for the prototype development.

The specifications of the portable power system are as specified in Table 3.2-1 below.

Table 3.2-1 Portable Power Supply Specifications

Part Number	Multi Power Pac
Manufacturer/Distributor	Battery Busters
Chemistry	Lead Acid
Output Voltage Range	3 to 24 VDC
Maximum Output Power	24 Watts
Capacity	5 Amp Hours at 8 VDC
Dimensions	6.75 x 3.375 x 1.5 in
Weight	1.09 kg
Accessories/Features	A/C Wall Charger Car Lighter Charger Charge Level Indicator

NOTE
The Multi Power Pac is not waterproof, do not immerse in water.

4. PRELIMINARY TESTING AND ANALYSIS

Several tests were conducted to validate the blower selection and system design. Each of the tests is described in detail below. The first test was conducted with a Size 7 Constant Wear Immersion Suit while subsequent tests were conducted with the Size 9 Modified Constant Wear Immersion Suit that was provided by the technical authority. Both suits were modified to integrate the blowers for test and evaluation.

4.1 Performance Validation for the Micronel Radial Blowers

A test was conducted to determine the suitability of the Micronel Miniature Radial Blower and the Multi Power Pac battery system to provide airflow against the back-pressure of the suit system. The test subject wore a Size 7 Constant Wear Immersion Suit with a trimmed neck seal to simulate the open area of an adjustable neck seal and a Size 9 Non-Uniform Breathable Foam Liner. No spacer fabric was used with the liner system. Figure 4.1-1 below is a schematic of the experimental setup.

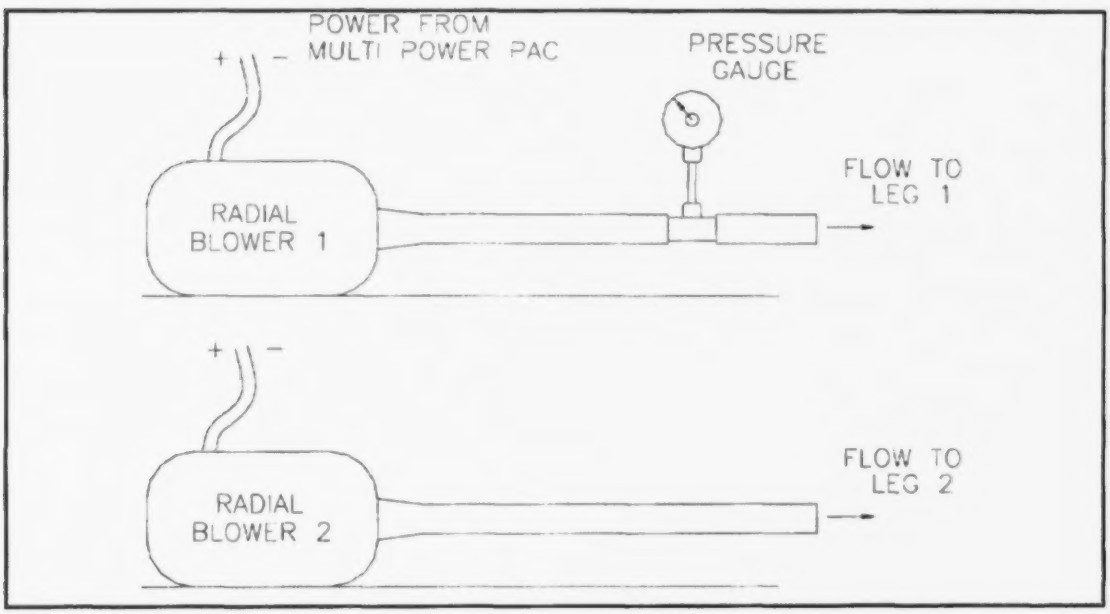

Figure 4.1-1 Back-Pressure Experimental Setup with Portable Blowers

The following basic assumptions were made for this experiment:

- Both blowers would operate at the same performance level due to the symmetry of the suit and blower systems;
- In lieu of the first assumption, the pressure measurement from one blower would be valid for both blowers; and

- The manufacturer's blower performance curve could be used to predict the airflow rate corresponding to the measured pressure. The performance curve is included at the end of the report as Appendix A.

Table 4.1-1 below provides the results of the experiment for the various configurations of the suit system.

Table 4.1-1 Back-Pressure and Airflow in the Suit System with Micronel Blowers

Configuration	Pressure [in H_2O]	Airflow* [CFM]
Constant Wear + Non-Uniform Breathable Foam Liner		
Standing	1.11	16.75
Sitting	2.22	11.75
Constant Wear + Non-Uniform Breathable Foam Liner + CF LP/SV		
Standing	2.50	10.25
Sitting	3.06	6.25
Constant Wear + Non-Uniform Breathable Foam Liner + CF LP/SV + PCU-15/P Harness		
Standing	2.50	10.25
Sitting	3.33	3.25
*As predicted from the manufacturer's performance curve.		

It was clear during the test that as successive components of the aircrew ensemble were included, the internal pressure increased causing an associated decrease in the airflow rate through the system. The pressures measured during this experiment were markedly lower than in the preliminary investigation of the system back-pressure. This is because the Micronel blower is only capable of providing airflow up to a static pressure of approximately 3.62 in H_2O. It was noted during the experiment that the subject could detect very little airflow when the pressure measurement was in excess of 3.00 in H_2O. It is hypothesized that additional losses in the system that could not be accounted for had reduced the maximum static pressure available from the blower. Hence it is likely that the predictions for the associated airflow would appear more favorable than that which actually occurred experimentally. It was concluded that without spacer material integrated into the suit system, the Micronel blowers would not be capable of providing sufficient airflow in the highly restrictive configurations.

4.2 Evaluation of a Simulated Spacer Fabric Liner

It was desirable to quantify the impact of compression of the suit due to the complementary aircrew life support equipment, namely the LP/SV and the harness. It is known that other aircrew suit systems have implemented various types of spacer materials to improve airflow conditions [9, 10, and 11]. The use of spacer fabrics in the liner system would ideally alleviate the back-pressure sufficiently to permit the Micronel blowers to provide airflow in all of the different configurations of the suit system. A spacer liner was simulated by covering the torso, arms and legs of a subject with highly porous half-inch spacer material in lieu of the Non-Uniform Breathable Foam Liner. The internal pressure and airflow through the suit system in the various configurations were then measured as described in the previous section; that is using the Micronel radial blowers. The test subject wore the Size 9 Modified Constant Wear Immersion Suit. A significant difference was noted in the internal pressure of the system in the various configurations. The spacer material permitted a dramatic increase in airflow through the suit system when compared to the system using the Non-Uniform Breathable Foam Liner as described in the previous section. Both the pressure measurements and subjective comments from the test subject evidenced the increased airflow. Figure 4.2-1 below shows the difference in back-pressures for the two configurations, Non-Uniform Breathable Foam Liner and simulated full coverage spacer liner.

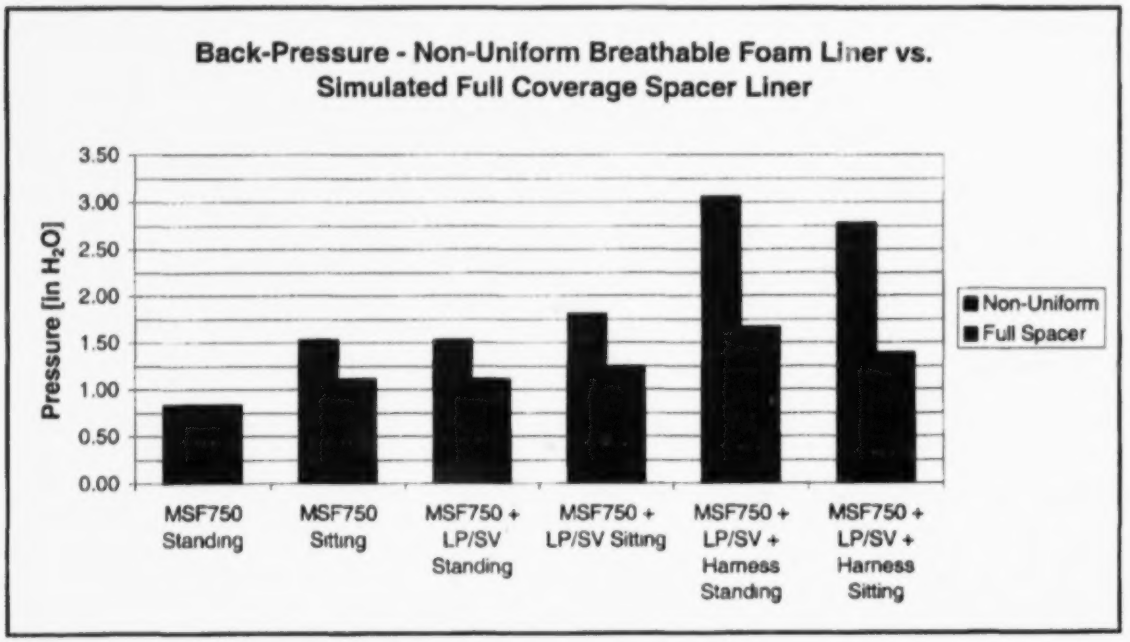

Figure 4.2-1 Effect of a Simulated Full Coverage Spacer Liner in Lieu of the Non-Uniform Breathable Foam Liner

This experiment validated the use of spacer material in suit liner systems for reduction of the internal back-pressure. Furthermore, the Micronel blowers were proven to provide sufficient airflow in each configuration with the presence of spacer fabric. However, there are many drawbacks associated with the use of such materials in garment systems. The spacer fabric has an uncomfortable abrasive surface and it is very stiff causing reduced maneuverability and donning difficulties. Furthermore, it may be complicated to manufacture liners that are entirely composed of such spacer fabrics. It is hypothesized that the use of spacer material is critical in only those regions where flow is restricted by additional aircrew life support equipment or by compression such as when sitting. The most strategic positions would likely include the chest and leg/thigh regions where the chest and leg/crotch straps of the CF LP/SV and the harness system are adjusted firmly to the subject's body.

4.3 Evaluation of Back-Pressure with Strategically Placed Spacer Fabric

A test was conducted to verify the hypothesis that spacer fabric would not be required over the entire body to improve airflow; rather a hybrid Non-Uniform Breathable Foam Liner with regions of spacer could achieve sufficient pressure reduction for the Micronel blowers. Again the apparatus shown in Figure 4.1-1 was used for the experiment. The subject was tested wearing the Size 9 Modified Constant Wear Immersion Suit and a Size 9 Non-Uniform Breathable Foam Liner. Half-inch spacer fabric was attached to the front of the liner over locations suspected of being highly susceptible to interrupted airflow such as the knees, the upper thigh or hip, the abdomen and the chest. Figure 4.3-1 below provides an indication of the placement of the spacer fabric.

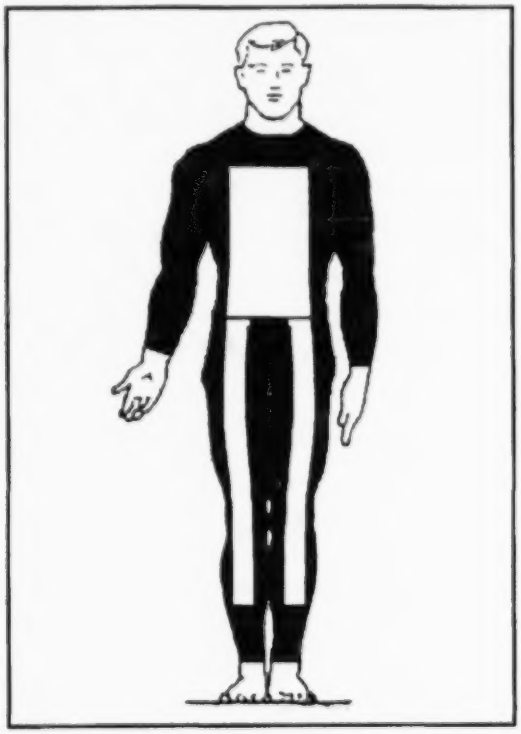

Figure 4.3-1 Spacer Fabric Placement

Figure 4.3-2 below is a plot of the back-pressure reduction with spacer when compared with the Non-Uniform Breathable Foam Liner System. As expected the measurements from the experiment indicated that a significant reduction of back-pressure is possible in the various configurations when compared to the Non-Uniform Breathable Foam Liner system. However, only one subject was tested in this manner and extensive testing would be required to determine the statistical significance due to the highly fit dependent nature of these results. The subject indicated that an improvement in flow was noticeable on the lower legs, around the knees, abdominal and groin.

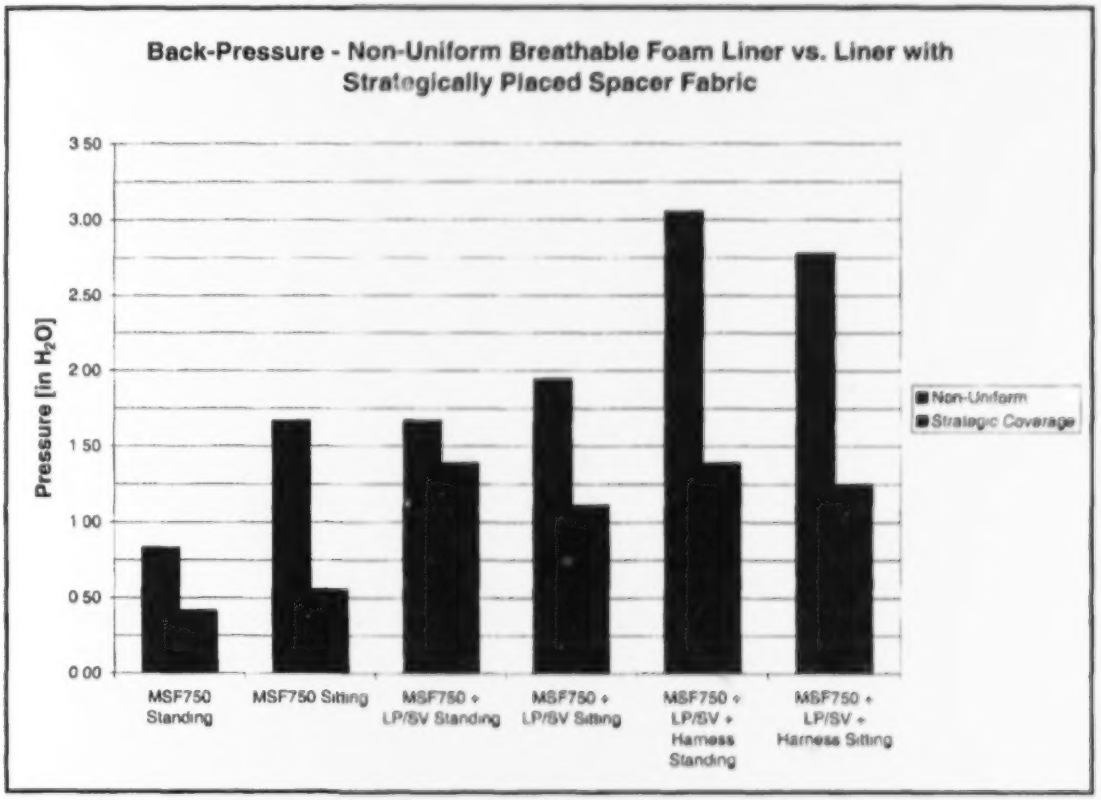

Figure 4.3-2 Effect of Strategically Placed Spacer Fabric on Back-Pressure

Figure 4.3-3 below is a plot comparing the back-pressure of the liner with strategically placed spacer with the simulated full coverage spacer liner. It is clear that the hybrid style of liner, as tested, provided comparable gains in pressure reduction when compared with a simulated full coverage spacer liner. The natural lie of the Constant Wear Immersion suit in the uncompressed areas allows relatively uninterrupted airflow and there does not seem to be any logical reasoning that would indicate a need for spacer coverage in these regions. In the regions that are compressed when in the seated position such as the thighs, buttocks and back it is undesirable to implement the spacer fabric because of the negative impact on comfort when resting against this type of material.

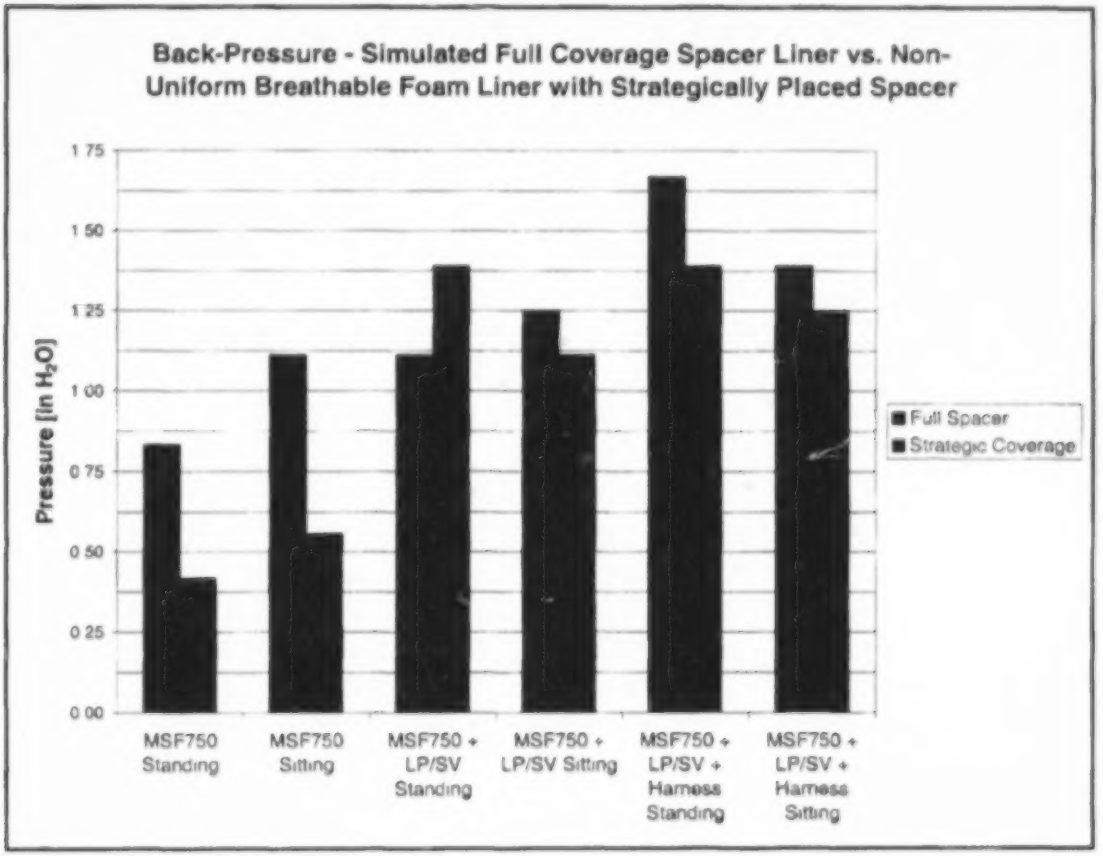

Figure 4.3-3 Comparison of Full Coverage with Spacer Fabric and Strategic Placement of Spacer Fabric

The flow associated with the highest back-pressure for the liner with strategic placement of spacer fabric, is approximately 16 CFM as predicted from the performance curve for

the Micronel blower. Due to pressure losses that were not accounted for upstream from the measurement location, the actual flow may be lower than that predicted from theory. Although the back-pressures appeared to be lowered significantly with such placement of spacer fabric, it is recommended that more extensive research would be required to determine the exact locations and appropriate dimensions required to achieve the best performance from such a hybrid liner.

5. PROTOTYPE DESIGN (SUIT MODIFICATION)

A Size 9 Modified Constant Wear Immersion Suit was provided to Mustang Survival by the technical authority. This suit was modified to incorporate the chosen blowers and portable power system. The final prototype system is shown below in Figure 5-1 and each of the components is described in the subsequent sections.

Figure 5-1 Final Prototype – Modified Constant Wear Immersion Suit System with Portable Blowers

5.1 Battery Pocket

The portable battery system was designed for mounting on the CF Helicopter Survival Vest (Survival Vest, Helicopter and Transport Aircraft, NSN 8415-21-907-9481). A custom pocket, with a slide fastener closure, was designed and fabricated for the battery. This pocket was then sewn onto a plastic backing plate for mounting directly to the CBR Blower bracket on the front left side of the vest. The plastic backing plate consists of a bayonet style clip that slides into the receiver on the vest and two metal snap fasteners that secure the entire assembly. There are two drainage grommets at the bottom edge of the pocket and a third for routing the wiring harness to the blowers. A rotary style switch and a connector were added to the battery back power cord to ease connection and operation of the blower system. The integrated battery pocket is shown in Figure 5.1-1 below.

Figure 5.1-1 Survival Vest with Integrated Battery Pocket

5.2 Blower Pockets

The blowers are mounted on the lower regions of the legs. To facilitate the installation of the blowers, the "Plain Pocket" [4] on each shin was removed and replaced with a custom blower pocket. The blower pockets are constructed with Aramid mesh side panels and an Aramid fabric top panel. There is a strap incorporated into the top of the pocket that serves as both the pocket closure and a securing system to hold the

blowers firmly in place. It is fastened with a metal snap. The blower is installed in the pocket with the motor protruding from a hole in the center of the pocket. The blower inlet, on the opposite side, faces the leg and half-inch spacer fabric has been used to permit sufficient airflow into the system. The wiring passes through a grommet, to the outside of the leg and into the wiring tunnel that is sewn into the leg seam. The blower outlet faces up the leg towards the knee and has been integrated to the suit entry port with a heat shrink material. Figure 5.2-1 below is a photo of the blower pocket showing the inlet port and the bottom segment of the wiring tunnel.

Figure 5.2-1 Blower Pocket with Inlet Port and Wiring Interface

5.3 Wiring Tunnel

Wiring tunnels have been incorporated into the outside of each leg seam of the Modified Constant Wear Immersion Suit. The leg tunnels extend from the shin area up to approximately one-inch from the waist seam interface. A third wiring tunnel is sewn across the waist/abdomen seam so that the wire harness from the right side may be routed to mate with the harness at the left side. Both sets of wiring merge at a connector that is used to interface the power supply system with the blowers.

5.4 Entry Port

Entry ports were installed directly above the outlet of the blower and below the knee on the Modified Constant Wear Immersion Suit. A one-inch polyurethane elbow (13/16-

inch inner diameter) was used to port the air from the blowers and into the suit. The elbow was welded to the suit over a location that had been laminated with polyurethane film to facilitate this process. As stated above, the entry port mates directly with the blower outlet and the two are sealed together with a heat shrink material.

5.5 Liner Modifications

A Size 9 Non-Uniform Breathable Foam Liner was provided to Mustang Survival for modification with spacer fabric to reduce the back-pressure of the suit system. Preliminary testing indicated that placing half-inch spacer fabric on the front of the body over the legs and torso, as indicated previously in Figure 4.3-1, permitted airflow past areas of the suit that were highly compressed by the LP/SV and harness. The liner was modified to integrate the spacer material directly for final testing and evaluation of the prototype. Figure 5.5-1 below is a photo of the modified liner.

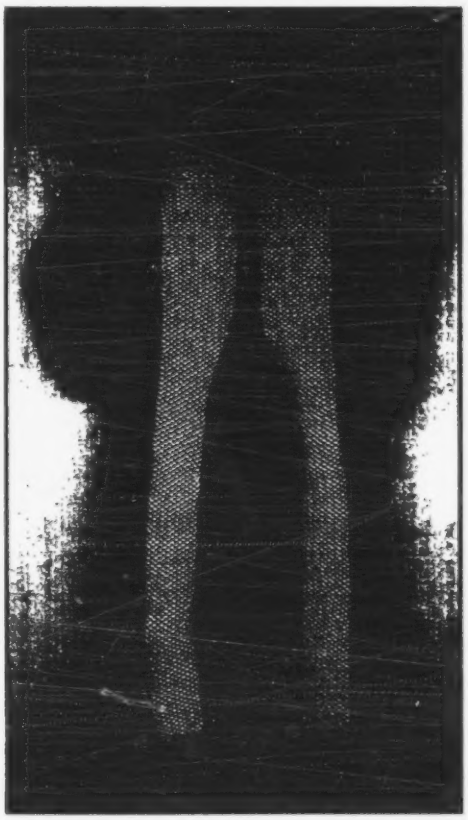

Figure 5.5-1 Size 9 Non Uniform Breathable Foam Liner Modified to Incorporate Spacer Fabric

A five-inch strip of the outer shell Nomex® and foam was removed from the liner along the center-line of the each leg tapering out to seven inches over the torso of the liner on each side of the zipper. The inner Britex® lining was left intact to maintain a comfortable and smooth finished material between the spacer fabric and the skin of the user. Half-inch spacer fabric was then sewn into the cutaway portions of the liner with the edges sewn into a binding to prevent snagging of the sharp edges.

It is hypothesized that the Britex® lining will absorb perspiration from the aircrew and the airflow from the blowers will travel over the lining enhancing the evaporative heat loss. Furthermore, because the Britex® lining is also air permeable, a percentage of the airflow will pass through the liner and over the skin as it travels through the suit thereby providing an additional component of convective heat transfer from the skin. High sweat rates will lead to increased wicking to the outer layer of the Non-Uniform Breathable Foam Liner in all regions, which will also benefit the evaporative heat loss due to the internal airflow. Additional human subject testing is required to determine the extent of cooling that may be achieved from the proposed suit system configuration.

6. FINAL PROTOTYPE TESTING AND EVALUATION

The Size 9 Modified Constant Wear Immersion Suit was retrofitted to incorporate portable blowers in the lower regions of the legs. To enhance airflow within the system, a Size 9 Non-Uniform Breathable Foam Liner was modified to incorporate spacer fabric over the front of the liner. The following provides details of the back-pressure analysis of the final prototype system as well as a preliminary report on the potential thermal benefit of the system.

6.1 Back-Pressure

The back-pressure of the final suit configuration was tested on a subject using the apparatus depicted in Figure 4.1-1. The system consisted of a Size 9 Modified Constant Wear Immersion Suit including the portable blowers integrated to the leg regions, a Non-Uniform Breathable Foam Liner modified to incorporate spacer fabric as discussed previously, a CF LP/SV and a PCU-15/P Parachute Harness. The measurements of the back-pressure and the corresponding airflow are shown in Table 6.1-1 below. The airflow's presented in the table are as predicted from the blower curve provided by the manufacturer.

Table 6.1-1 Back-Pressure and Airflow in the Final Prototype System

Configuration	Pressure [in H_2O]	Airflow* [CFM]
Modified Constant Wear Immersion Suit + Non-Uniform Breathable Foam Liner with Spacer		
Standing	0.28	19.75
Sitting	0.42	18.85
Modified Constant Wear Immersion Suit + Non-Uniform Breathable Foam Liner with Spacer + LP/SV		
Standing	0.97	17.25
Sitting	1.25	16.50
Modified Constant Wear Immersion Suit + Non-Uniform Breathable Foam Liner with Spacer + LP/SV + Harness		
Standing	1.94	13.25
Sitting	1.53	15.00
*As predicted from the manufacturer's performance curve.		

During the test, the subject indicated that a noticeable airflow was detected in each of the test configurations. The test data supported this qualitative evaluation as the final prototype suit system exhibited back-pressures significantly lower than the system with an unmodified Non-Uniform Breathable Foam Liner and back-pressures comparable to the simulated full coverage spacer liner. Although the measured back-pressures for the final prototype were in some cases lower than those measured for the simulated full

coverage spacer liner, it is important to note the highly fit and size adjustment dependence of all of these experimental results. Additional testing with several test subjects is required to determine the statistical significance of the data reported herein. Figure 6.1-1 below depicts the back-pressure of the final prototype system when compared to the unmodified Non-Uniform Breathable Foam Liner system and Figure 6.1-2 is a comparison of the prototype system and the simulated full coverage spacer liner.

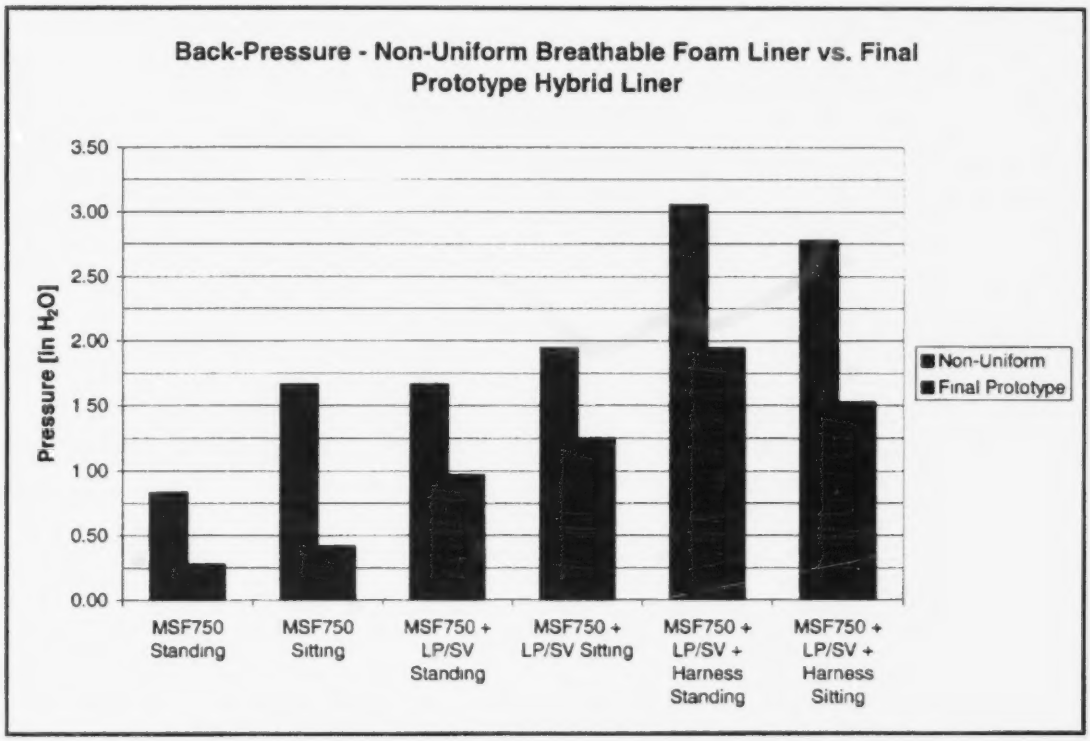

Figure 6.1-1 Back-Pressure Comparisons of Non-Uniform Breathable Foam Liner and Final Prototype Hybrid Spacer Liner

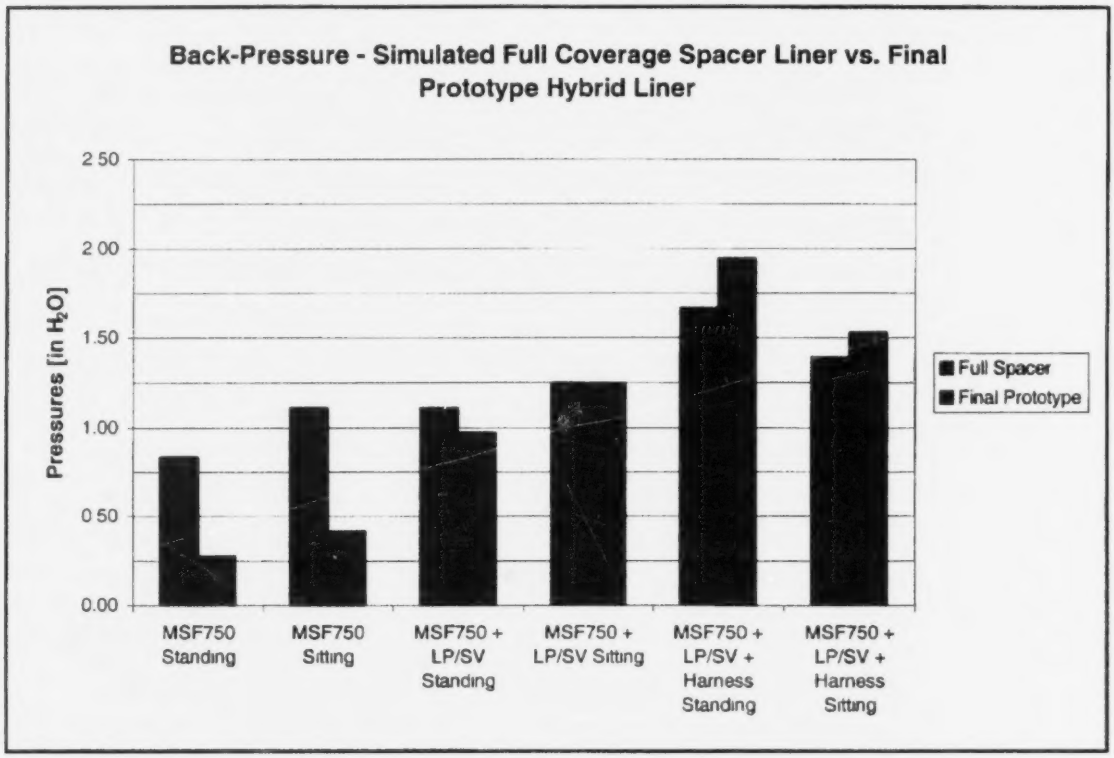

Figure 6.1-2 Back-Pressure Comparisons of Simulated Full Coverage Spacer Liner and Final Prototype Hybrid Liner

6.2 Thermal Benefit

A preliminary thermal evaluation was conducted to provide evidence that the prototype system using unconditioned ambient air would enhance the heat loss of the subject thereby reducing the thermal burden.

A thermal evaluation was conducted on a single test subject wearing a Size 9 Modified Constant Wear Immersion Suit with portable blowers and a Size 9 Non-Uniform Breathable Foam Liner with integrated half-inch spacer material. The subject was also fitted with an CF LP/SV and PCU-15/P Parachute Harness. Two test profiles were selected for evaluation. During the first profile the subject wore the aircrew ensemble in an ambient environment for one hour with the portable blowers turned off. During the second profile the subject wore the ensemble for one half hour with the portable blowers turned off followed by one half hour with the blowers turned on. Unconditioned air was provided to the blowers. The subject was seated for the duration of both tests and performed no work so that the conditions of the test could be easily replicated. The

environment during both experiments approached conditions of standard temperature and relative humidity (25°C, 50% RH). Heat flux and skin temperature measurements were taken simultaneously from the following locations on the body: chest (right pectoral muscle), arm (right lateral biceps), mid-back (right), calf (right lateral) and thigh (right anterior). Figures 6.2-1 and 6.2-2 are plots of the mean skin temperature and heat flux measurements for the two tests.

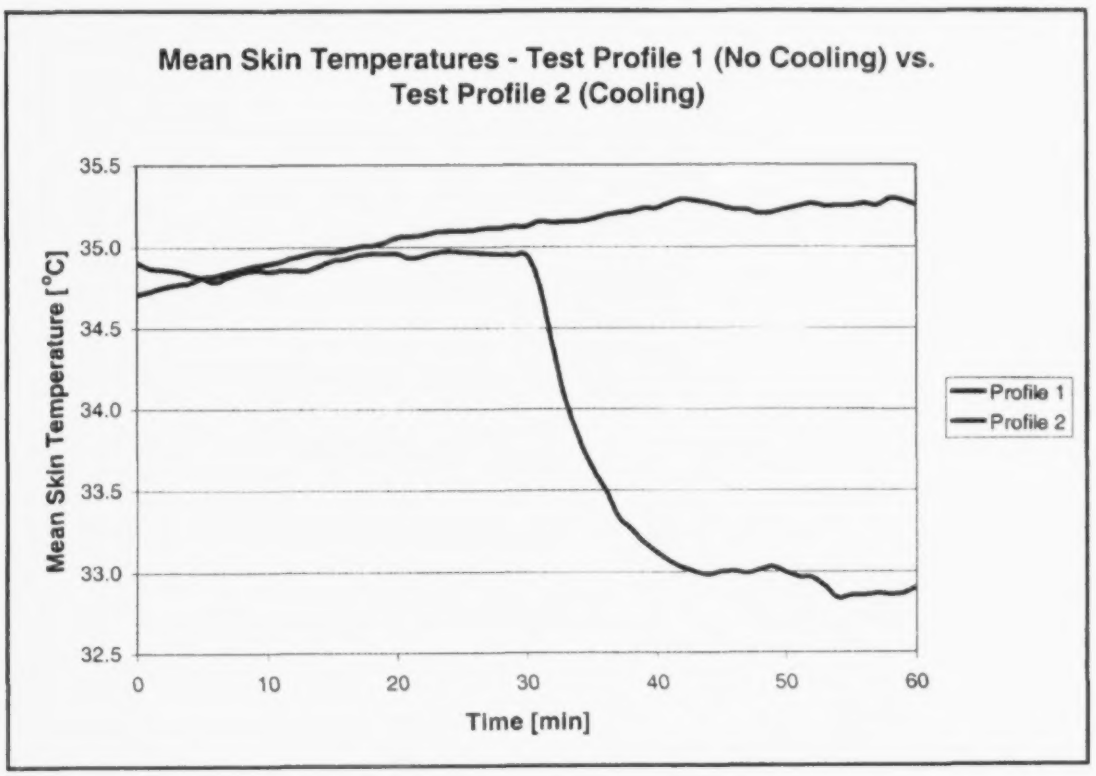

Figure 6.2-1 Comparison of Mean Skin Temperatures without and with the Portable Cooling Blowers Operating

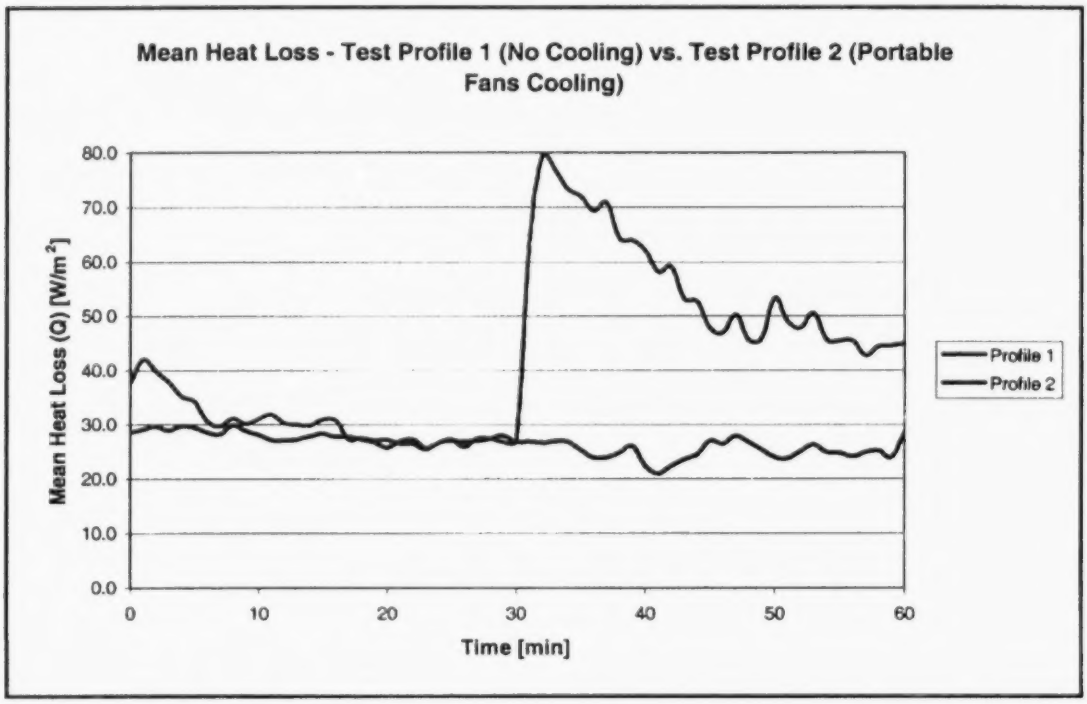

Figure 6.2-2 Comparison of Mean Heat Flux without and with the Portable Cooling Blowers Operating

Both plots of the experimental data on both figures exhibit very similar characteristics during the first half-hour as expected from theory. The data then clearly shows a marked decrease in the mean skin temperature and an associated increase in the mean heat loss at the point when the cooling blowers were turned on. The mean heat loss then declined following a typical Newtonian profile as drying at the skin occurred. At one hour the mean heat loss had approached a near steady state condition and a mean heat loss increase of approximately 80% (20 W/m^2) was noted for the profile that included operation of the portable blowers. It is hypothesized the that use of conditioned air in ambient environments of higher temperatures will result in more significant heat loss and skin temperature gradients.

The preliminary evaluation of the thermal benefit of the addition of portable blowers to the leg regions of a Modified Constant Wear Immersion Suit exhibited positive results. The test subject indicated a clear improvement in comfort level during the experimental profile that provided cooling. However, because only one subject was tested the results of this experiment are inconclusive and require validation through more extensive human subject testing.

7. CONCLUSION AND RECOMMENDATIONS

A Modified Constant Wear Immersion Suit with an adjustable neck-seal was modified to incorporate portable blowers into the leg regions. The purpose of the blowers was to distribute ambient air throughout the suit thereby displacing warm humid air from inside the suit out through the open neck seal. Several types of fans and blowers were investigated and the final selection for the suit system was a Micronel U97EM-012KK-3 Miniature Radial Blower. Blower pockets and inlet ports were fabricated for the prototype suit. The system is intended to be entirely portable and for this reason a portable power supply was also investigated. A rechargeable battery pack was purchased and integrated to the aircrew ensemble with a pocket that integrates to the Survival Vest on the CBR blower mounting plate.

Preliminary testing indicated that sufficient airflow is achieved within the suit system when spacer fabrics are strategically placed in compressed regions of the suit. Heat flux and skin temperature measurements on a test subject during a preliminary thermal study indicate that some level of physiological benefit may be realized from this suit system when circulating unconditioned air. It is hypothesized that providing conditioned air to the blowers would further enhance the cooling capabilities of this system. Subjects indicated a positive improvement in thermal comfort when wearing the prototype suit with the blowers operating as compared to the system without blowers.

The following are recommendations for future development to enhance the system performance of the Constant Wear Immersion Suit with Adjustable Neck Seal and blowers:

- Investigate the possibility of developing lower profile blowers with similar performance characteristics to those identified in this report;
- Investigate a portable power supply that is capable of supplying the correct regulated voltage for the blower system and with an appropriate capacity;
- Conduct extensive back-pressure testing on a variety of subjects to quantify the impact of fit on the performance of the system,
- Conduct extensive preliminary thermal testing to validate the capability to provide cooling of heat stressed subjects;
- Initiate a liner development to determine the exact locations and quantity of spacer fabric required to reduce the back-pressure of the suit system while maintaining aircrew comfort;
- Investigate water-activated cutoffs that would seal the suit system upon immersion;
- Determine the impact of the liner modifications on the cold water immersion protection of the suit system; and
- Conduct a cockpit compatibility study to determine the impact of the integrated fans on the crew workstation.

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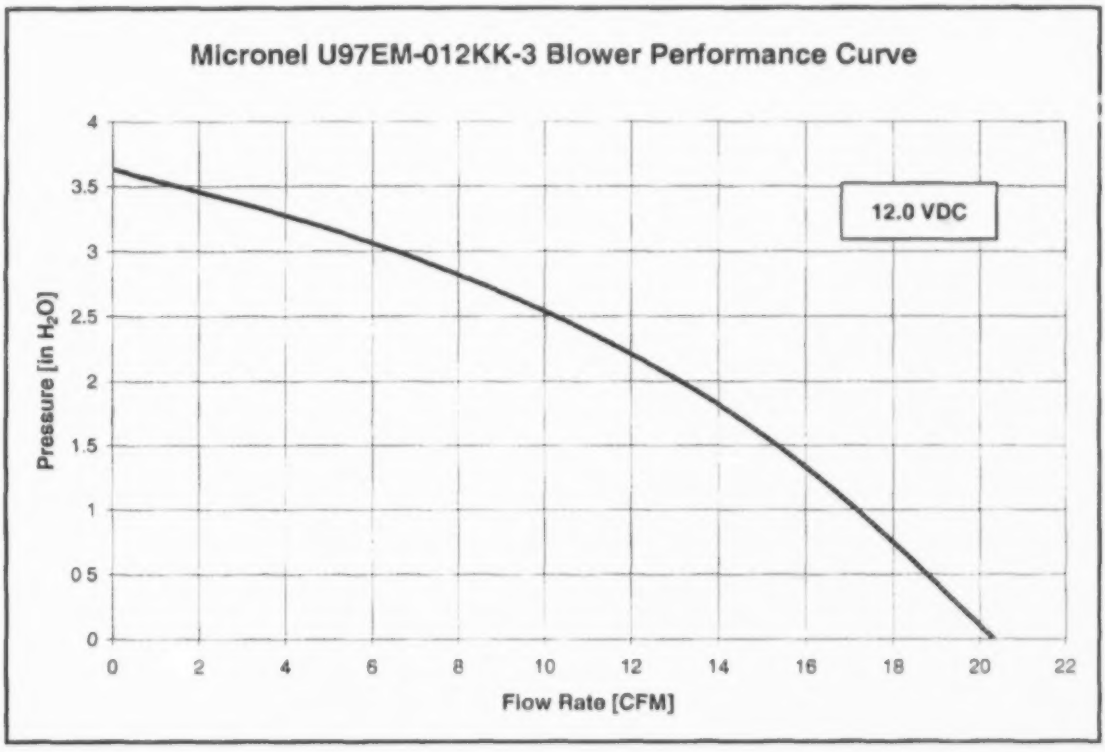
APPENDIX A

Micronel U97EM-012KK-3 Miniature Radial Blower Performance Curve



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human subject testing is required. A liner development would be prudent to identify the most efficient spacer configurations necessary to maximize the airflow in the system and an investigation is required to develop water activated flow interrupters to seal the suit upon immersion. Finally, the impact of the integrated blowers on cockpit compatibility would necessarily be addressed prior to certification for airworthiness.

(U)

15 KEYWORDS, DESCRIPTORS or IDENTIFIERS

(U) immersion suit, helicopter aircrew, cooling, heat stress